

"EARLY-LATE DETECTION"

#### CROSS-REFERENCES TO RELATED APPLICATIONS

- 5           This is a continuation-in-part of Application No.09/649672 filed August 28<sup>th</sup>, 2000 entitled "Tracking of a multi-path resolved signal in a rake receiver", incorporated herein by reference.

#### 10   FIELD OF THE INVENTION

          The invention relates to a method for tracking a resolved signal. The invention also relates to a rake receiver for tracking a resolved signal. The invention then concerns a computer readable medium for storing  
15   instructions for carrying out a method of the invention.

- The invention is relevant to communications over a cellular network using Code-Division Multiple Access technology for tracking delays of multipath signals from a base station to a mobile station. The invention may also be  
20   applied in a rake receiver in a mobile communication device for resolving and tracking arriving delays of multi-path components of a transmitted signal.

#### BACKGROUND ART

- 25           Various multiple-access technologies may be used for cellular communications.

- A first group of these technologies consists in narrowband channelized technologies such as the Frequency-Division Multiple Access (FDMA) technology and the Time-Division Multiple Access (TDMA) technology. In a FDMA  
30   communication system each user is assigned to a first specific frequency sub-band of the bandwidth reserved for

up-link communications (from a mobile station to a base station) and to a second frequency sub-band of the bandwidth reserved for down-link communications (from a base station to a mobile station). In a TDMA system each user is assigned to a different time slot and accesses the entire reserved sub-bands.

A second group of multiple-access communication technologies consists in wideband channelized technologies. Among these, the Code-Division Multiple Access (CDMA) technology has been widely adopted as a standard. CDMA allows each user to use the entire bandwidth for the complete duration of a call.

CDMA is a spread spectrum technology which means that the information contained in the information signal is spread over a much greater bandwidth than that of the original signal. In the Direct Sequence Spread Spectrum (DS-SS) technology, the information signal of data rate  $T_b$  is multiplied in the transmitter by a pseudo-random binary sequence, the code sequence, of clock period  $T$ , so-called the chip period, where  $T_b \gg T$ . This has the effect of increasing the bandwidth of the signal by the ratio  $T_b/T$ . The spread signal is then transmitted over the wider band with a reduced power spectral density relative to a corresponding de-spread signal. The code sequence is independent of the information signal and is known to the transmitter and the receiver.

At the receiver, the received wide-band spread spectrum signal must be de-spread in order for the information signal to be recovered. De-spreading is achieved by multiplying the spread signal by an exact replica of the code sequence used in the transmitter. The replica must be synchronized with the received spread

signal. A local code sequence generator that generates the code sequence at the receiver must be aligned and synchronized within one chip of the received spread signal.

Code synchronization may be performed in two stages: a  
5 code acquisition followed by a fine code tracking. Acquisition reduces the alignment timing offset between the received spread signal and the locally generated code sequence to less than a chip period. Tracking aligns and maintains the two signals synchronized.

10 In a real communication environment such as urban and suburban areas, radio signals are reflected and scattered off various objects along the transmission path between the transmitter and the receiver. Therefore the spread signal, mentioned above, encounters multipath when transmitted from  
15 the base station to the mobile station. In addition, phase cancellation of signals following different paths may cause severe fading and may lower the received signal power. However CDMA provides robust operation in fading environments. CDMA takes advantage of multipath fading to  
20 enhance communication and voice quality. For this purpose, a rake receiver is present in each mobile station and allows selecting the strongest multipath signals incoming from the base station. Transmission delays are estimated for the strongest multi-paths and the estimated delays are  
25 assigned to specific "fingers" of the rake receiver. A finger is a processing element that correlates the received spread signal with the replica of the locally generated code sequence on the basis of the estimated time delay assigned to the finger. The fingers' outputs are then  
30 weighted and then coherently combined to produce an enhanced signal. Thus, the multi-path nature of the channel is used to create a diversity advantage in CDMA.

International application WO 99/35763 discloses a method for estimating multipath delays of a direct spread spectrum signal transmitted in fading environments. Delays are estimated by measuring the envelope of the signal.

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#### SUMMARY OF THE INVENTION

It is an object of the invention to provide a different method for tracking multi-path components of a signal transmitted in a fading environment. It is another object of the invention to provide a rake receiver comprising rake fingers performing low computational early-late detection.

To this end, a method of the invention comprises:

determining a first value representative of an energy of the signal at a first instant before a presumed occurrence of a local optimum of the energy of the signal;

determining a second value representative of the energy at a second instant after the presumed occurrence of the local optimum;

calculating a first product of a first integer and the first value and calculating a second product of a second integer and the second value, with the first integer smaller than the second integer;

generating a first logical value from a comparison between the first and the second products;

calculating a third product from a third integer and the first value and calculating a fourth product from a fourth integer and the second value, with the third integer smaller than the fourth integer;

generating a second logical value from a comparison between the third and the fourth products; and,

generating a detector output signal from a difference between the first logical value and the second logical value.

A method of the invention allows tracking a signal using the first and second values of the energy without necessarily determining a metric involving a ratio of these two values that may be complicated to calculate and costly in terms of hardware. Such a method of tracking the signal does not require normalization of the first and second values of the energy of the signal. An advantage of one or more embodiments of the invention is to provide simple and efficient tracking.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in further detail, by way of example, and with reference to the accompanying drawing wherein:

Fig.1 is a conventional communication system;  
Fig.2 is a block diagram of a conventional receiver;  
Fig.3 is a block diagram of a conventional receiver;  
Fig.4 is a rake finger of a receiver of the invention;  
Fig.5 is a delay detector of the invention; and,  
Fig.6 is a diagram of the energy of a multipath component.

Elements within the drawing having similar or corresponding features are identified by like reference numerals.

#### PREFERRED EMBODIMENT

Fig.1 is a communication system 100 of the invention comprising a first transceiver 200 communicating with at least a second transceiver 300. The transceiver 200 may be

a base station and the transceiver 300 may be a mobile station such as a handset or a cell phone in a CDMA cellular communication system. The transceivers 200 and 300 comprise respective transmitters T200, T300 for

5 transmitting information signals and comprise respective receivers R200, R300 for receiving information signals. The transmitter T200 transmits via an antenna 210 an information signal S spread by correlation with a pseudo-random noise code sequence. The signal S was also  
10 previously modulated by correlation with a carrier signal of carrier frequency  $f_c$ . The spread signal S is received by an antenna 310 of the transceiver 300.

While transmitted from the transmitter T200 to the receiver R300, the signal S encounters multipath. In this  
15 embodiment, the signal S is reflected and scattered off a mountain 110 and a building 120. The spread signal S is the superposition of at least two multipath signals S1 and S2. The multipath signals S1 and S2 have different transmission paths and different transmission delays. The path  
20 attenuation and phase shift to which the signals S1 and S2 are subjected are assumed to be random-like and mutually independent. As a result the signal S can be thought as the superposition of a number of randomly attenuated and phase rotated signals containing among others the signals S1 and  
25 S2.

Fig.2 is a conventional block diagram of the receiver R300. The signal S transmitted from the base station 200 is received by the antenna 310 and inputted to a demodulation circuit 305 of the receiver R300. The signal S is passed  
30 through a RF receiver 320 and thereafter processed by a divider 330 for division into two radio signals I1 and Q1. The radio signal I1 is mixed in a mixer 340 with the

oscillator output  $f_c$  of an oscillator 360 resulting in an in-phase demodulated base-band signal I2. The radio signal Q1 is mixed in a mixer 350 with the oscillator output  $f_c$  shifted to  $\pi/2$  in a phase shifter 370 resulting in a quadrature demodulated base-band signal Q2. The base-band signals I2 and Q2 are then respectively passed through low pass filters 380 and 390 for providing channel selectivity. Both filtered signals I and Q are then provided to a rake receiver 400 for multi-path components resolving and diversity combining into a signal R.

Fig.3 is another block diagram of the receiver R300. The receiver R300 comprises the demodulation circuit 305 for extracting the in-phase and quadrature components I and Q further transmitted as a complex signal  $S^*$  to the rake receiver 400. The rake receiver 400 comprises three rake fingers 410, 412, 414. Each finger 410-414 is assigned a multi-path component S1, S2 and S3, respectively, of the received signal S for acquisition and tracking. The rake receiver 400 also comprises a maximal ratio combiner 420 for combining the multi-path components S1-S3 resolved by the fingers 410-414 to provide diversity. The resulting signal is the signal R.

Fig.4 is a circuit block diagram representing one example of a structure of the rake finger 410-414 of the invention. Initially the rake finger 410-414 adopts an acquisition mode. Acquisition is performed in the acquisition unit 422 for synchronizing a replica of the code sequence, originally used to spread the information signal, with the multi-path component S1-S3 assigned to the finger 410-414. The replica of the code sequence is generated in a pseudo-noise generator 424.

Thereafter, in a tracking mode, the rake finger 410-414 maintains the generated code sequence aligned to the assigned multi-path component S1-S3. The base-band signals I and Q are provided as the complex input signal  $S^*$  to the rake finger 410-414. The signal  $S^*$  is then branched in two branches for determining early and late components E and L representing respective early and late reception of the assigned signal component S1-S3 with respect to a presumed reception of the signal S1-S3 which is represented by a peak of the energy of the assigned signal S1-S3.

In a first branch, the early component E is determined by correlating in a mixer 428 the signal  $S^*$  with the code sequence taken at a first instant  $t_E$  before the presumed peak of the energy of the signal S1-S3. The early component E is then determined by processing the output signal of the mixer 428 in a low-pass filter 432 and by complex magnitude squaring in a squared arrangement 436. As shown in Fig.6, a presumed peak of the energy of the assigned signal S1-S3, represented in dashed line, is expected to occur at instant  $t_0$ . The component E is representative of the energy of the signal S1-S3 taken at the first instant  $t_E$  before the presumed occurrence at  $t_0$  of the optimum of the energy of the signal S1-S3.

Symmetrically, the late component L is derived by first correlating in a mixer 426 the signal  $S^*$  with the code sequence taken at a second instant  $t_L$  after the presumed occurrence of the maximum. The late component L is then determined by processing the output signal of the mixer 426 in the low-pass filter 430 and by complex magnitude squaring in a squaring arrangement 434. The component L is representative of the energy of the signal S1-S3 taken at the second instant  $t_L$  after the presumed



occurrence at  $t_0$  of the optimum of the energy of the signal S1-S3.

The early and late components E and L are then inputted to a delay detector 500 that processes the two components E and L and determines the early-late state of the reception of the assigned multi-path component S1-S3 indicated by an early-late signal V. In this embodiment the delay detector 500 is a digital signal processing unit. The signal V is then provided to a loop filter 438 where an appropriate correction signal CORR is derived and transmitted to the pseudo-noise generator 424. The correction signal CORR allows monitoring the phase of the code sequence so that the code sequence is kept synchronized with the assigned component S1-S3.

An information signal is then obtained from the multi-path signal S1-S3 at the output of a mixer 420. The mixer 420 allows de-spreading the assigned component S1-S3 of the signal  $S^*$  by correlating the signal  $S^*$  with the code sequence aligned to the multi-path signal S1-S3.

A detailed embodiment of the detector 500 is given in Fig.5. The detector 500 comprises a calculating unit 510, a calculating unit 530 and a logical comparator 550 for providing a logical signal V1. The signal V1 is obtained from a comparison of a first product  $K_1 \cdot E$  of the early value E and an integer  $K_1$  derived in the unit 510 with a second product  $K_2 \cdot L$  of the late value L and an integer  $K_2$  derived in the unit 530. In this embodiment  $K_1$  is smaller than  $K_2$  ( $K_2/K_1 > 1$ ). V1 is 1 when  $K_2 \cdot L > K_1 \cdot E$  is true as shown in Table 1, V1 is 0 otherwise. V1=0 indicates that  $E/L > K_2/K_1 > 1$ , i.e. the tracking of the assigned component S1-S3 is early.

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The detector 500 further comprises a calculating unit 520, a calculating unit 540 and a logical comparator 560 for providing a logical signal V2. The signal V2 is obtained from a comparison of a first product  $K3 \cdot E$  of the early value E and an integer K3 derived in the unit 520 with a second product  $K4 \cdot L$  of the late value L and an integer K4 derived in the unit 540. In this embodiment K3 is smaller than K4 ( $K3/K4 < 1$ ). V2 is 1 when  $K4 \cdot E > K3 \cdot L$  is true as shown in Table 1, V2 is 0 otherwise. V2=0 indicates that  $E/L < K3/K4 < 1$ , i.e. the tracking of the assigned component S1-S3 is late.

The units 510-540 may be implemented as logic gates in the form of ICs or alternatively the functions carried out by the units 510-540 may be fulfilled by means of instructions in a software component.

The signals V1 and V2 are combined in an adder 570. The adder 570 allows calculating the value of the signal V of the expression  $V1 - V2$ . The value of the signal V is given in Table 1 depending on the position of E/L with respect to the values  $K3/K4$  and  $K2/K1$ .

	$E/L < K3/K4 < 1$	$K3/K4 < E/L < K2/K1$	$E/L > K2/K1 > 1$
V1	1	1	0
V2	0	1	1
V	1	0	-1

Table 1

V=1 indicates that the tracking of the assigned component S1-S3 is late. V=0 indicates that tracking of the assigned component is quite on-time. V=-1 indicates that tracking of the assigned component is early or in advance.

K1, K2, K3 and K4 may be arbitrarily chosen with  $K1 < K2$  and  $K3 < K4$ . K1 and K3 may be chosen such that  $K1 = K3$  and K2

and K4 may be chosen such that  $K2=K4$ . For example,  $K1=K3=2$  and  $K2=K4=3$  allow a simple implementation of the units 410-440 using a limited number of logic gates. The integers K1, K2, K3 and K4 may be fixed to different constants depending on the sensitivity required for the early-late detection. The values for  $K1=K3$  and  $K2=K4$  may be chosen greater to reduce the on-time zone and to permit sensitive phase control of the code sequence generator 424.

It is to be noted that, with respect to the described method and communication system, modifications or improvements may be proposed without departing from the scope of the invention. For instance, it is clear that this method may be implemented in several manners, such as by means of wired electronic circuits or, alternatively, by means of a set of instructions stored in a computer-readable medium, said instructions replacing at least a part of said circuits and being executable under the control of a computer or a digital processor in order to carry out the same functions as fulfilled in said replaced circuits.

In view of the foregoing it will be evident to a person skilled in the art that various modifications may be made within the spirit and the scope of the invention as hereinafter defined by the appended claims and that the invention is thus not limited to the examples provided. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim.